Observations on Space Debris tracking with Multi Object Tracking Radar

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Abstract:
Multi Object Tracking Radar (MOTR) is an L-Band Active Phased Array Radar realized by Satish Dhawan Space Center (SDSC SHAR) with the main objective of tracking $0.25m^2$ sized space debris in LEO up to an altitude of 800km. MOTR is located in Sriharikota the space port of India at 13^0 44' 7.8396" N & 80^0 11' 4.5528" E . It is the first radar system in India realized for tracking space debris. It is commissioned and made operational on March 2015. MOTR had a dedicated space debris tracking campaign on July – Aug 2016 and tracked 51 different space objects during the campaign. From then MOTR is regularly being used for tracking various space debris. This paper reports the observations on the space debris tracking trials, processing of the MOTR tracked data for Orbit Determination and TLE generation. Preliminary accuracies achieved in orbit determination are also discussed.

Key words: Active Phased Array Radar, MOTR, Space Debris, LEO, Orbit Determination, TLE.

INTRODUCTION

Since the launch of Sputnik I in 1957, various space agencies has launched more than 6500 satellites, out of which more than 4500 satellites has reached their satellite life, lost their control and has become debris. A new set of debris has evolved in these five decades due to the explosion of spent rocket bodies or the non-active satellites which are in the orbit yet. The two major incidents Cosmos and Iridium collision and Chinese satellite missile test have increased the fragments of debris in LEO drastically [1-3]. This has caused a serious threat to space operating countries and agencies to safe guard their space assets against these debris. ISRO has started their works on space debris close approach analysis for Indian space assets and are being regularly used for the launch and satellite operation. ISRO activity on Space debris measurement is initiated through space debris monitoring and tracking with MOTR.

MULTI OBJECT TRACKING RADAR (MOTR)

Multi Object Tracking Radar (MOTR) is an L-Band Active Phases Array Radar with 4608 TR modules designed for tracking multiple targets using single agile beam with electronic Beam Steering technique. MOTR is capable of tracking multiple targets of size $0.25m^2$ target up to a range of 1000 km. Main objective of MOTR is to utilize its long range skin mode tracking capability to track space debris up to an altitude of 800km. Detailed specifications of MOTR are given below.

Fig.1. Multi Object Tracking Radar (MOTR)

SPECIFICATIONS

Frequency	: 1.3 – 1.4 GHz
Array Type	: Rectangular Planar.
Radiating Element	: Micro Strip Patch.
Antenna Size	: 11.33m * 5.66m.
Radiating Elements	: 4608.
Antenna Gain	: 39.4 dB.
Beam width	:AZ:1.1 Deg, EL:2.1 Deg.
Scan Coverage	
Electronic	: AZ: ±60, EL:±45deg.
Mechanical	: AZ: 0 – 360, EL:0 – 90 deg.
Pulse Width	: 10us to 2ms.
PRF	: 50 Hz to 10 kHz.
Pulse Compression	: 8000
Operating Modes	: Surveillance, Cued Search & Dedicated Track.
Multi Target Tracking	: Single agile beam on time shared basis.

MOTR is qualified by tracking targets like High altitude balloons with corner reflector and aircrafts prior to space objects tracking. Simultaneous Multi-target tracking is demonstrated by tracking multiple aircrafts simultaneously and by tracking both forward moving and spent down stages of a launch vehicle. Range tracking capability of MOTR is qualified by tracking a known RCS target (RIGIDSPHERE-2, NORAD ID: 05398) and validating the Received Signal strength against the expected signal strength at various ranges.

MOTR - DEBRIS TRACKING CAPABILITY

The current capability of radars and optical sensors to track debris is to 1m size debris in GEO, and 10 cm size debris in LEO. Any debris below these sizes is characterized as debris flux [1]. MOTR space debris tracking capability based on its link margin for various target size ie. Maximum slant range tracking capability for various size of spherical target is given in fig.2. MOTR can track a spherical target with diameter 40 cm and 60 cm up to a slant range of 1000 km and 1250 km respectively. Considering minimum track duration requirement as 120 sec for orbit determination, MOTR can track space objects of 0.13, 0.8 & 1.2 m^2 Radar Cross Section (RCS) at an orbital altitude of 400, 600 & 800 km respectively.

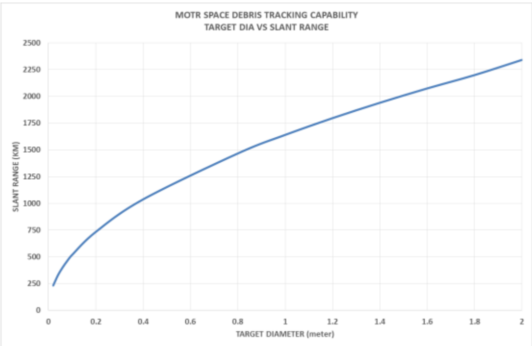

Fig.2 Range Tracking capability of MOTR as a function of Target Diameter.

SPACE DEBRIS TRACKING

Space objects are mostly categorised in to three, (1) active and dead satellites, (2) left over rocket bodies after each missions and (3) fragments created due to explosion or collisions.

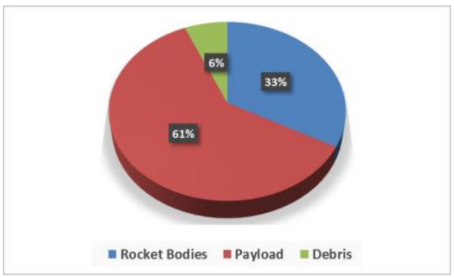

Fig.3. Space Objects distribution in LEO (< 800 km) with RCS catagorised as LARGE.

Space Debris in LEO is generally tracked by the radars, and the debris in Geostationary Earth Orbit (GEO) is tracked using optical telescopes [4]. Total space objects count within LEO of 800 km altitude is 733 (as on Aug 2017). Fig.3 shows the share of payloads, Debris and rocket body with large RCS in the total of 733 objects assigned by NORAD with in 800 km LEO orbit. Fig.4 shows the distribution of payloads (active satellites), spent down stages (Rocket bodies) and debris for various altitudes up to 800 km.

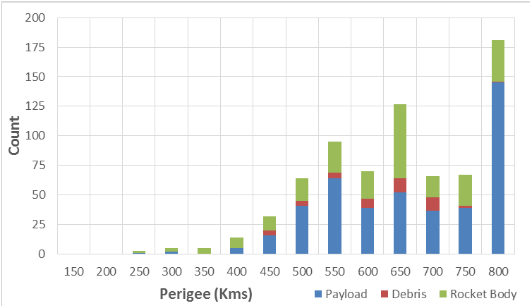

Fig 4. Space Objects count in LEO less than 800 km.

OBSERVATIONS ON SPACE DEBRIS TRACKING

The tracking of space debris is implemented by USA, Russia, ESA and Japan so far. In India, space debris observation and tracking started with MOTR on May 2015. With this ISRO started tracking and building their own catalogue of Space debris. Space debris tracking trials with MOTR was started by considering the debris in LEO orbit below 800 km altitude with RCS categorized as large in North American Aerospace Command (NORAD) catalogue [5-6]. There were 733 objects (as on Aug 2016) catalogued as large below 800 km altitude. Though RCS information is not a part of TLE, it was collected from various other sources, and the objects with very large RCS like ISS (25544), TIANGONG-1 (37820) and HST (20580) were attempted and tracked first.

TRACKING TRIALS

The first space object tracked by MOTR was ISS (25544) on 27th May 2015. We could track ISS from 400 km to 1130 km in range. MOTR had a dedicated space debris tracking campaign on July – Aug 2016 and could track 51 different space objects during this period. These tracking were set as a test to figure out how long we can reach and how small we can detect and accurate we can observe and track. The tracked data of each target is processed for Orbit Determination (OD) and Two Line Element (TLE) generation. Since ISS is the target with higher RCS, it had a longer skin mode tracking duration. Hence initial few tracking were made with ISS to collect more data for OD. Gradually more debris were attempted to track. Table.2 gives the list of Space debris tracked by MOTR during the tracking campaign. Out of 29 spent down final stage PSLV_RB of the PSLV missions in space, 15 were tracked and catalogued. Fig.5 shows the real time ground trace plot of PS4 stage of PSLV-C29 mission debris, PSLV_RB (41172) and Fig.6. Shows its generated orbit with the MOTR tracked data. Fig.7 gives the distribution of space objects tracked by MOTR during the campaign.

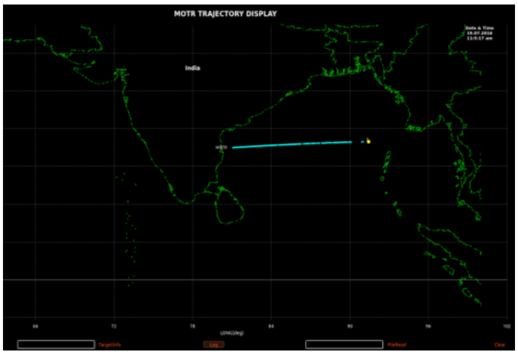

Fig.5. Real time tracked ground trace of PSLV_RB (41172) and its generated orbit.

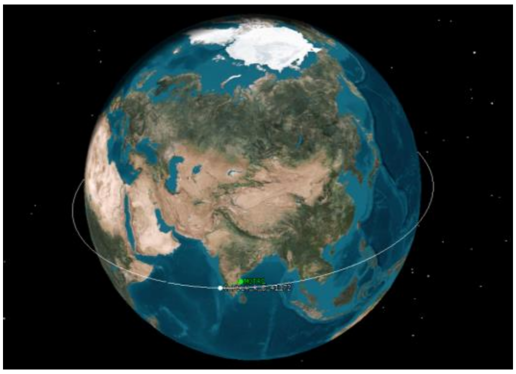

Fig.6 Generated Orbit for PSLV_RB (41172).

Table.2 List of Space Objects tracked by MOTR.

NORAD	NAME	Apogee (km)	Perigee (km)	i (deg)	Period (rev/day)	Passes Tracked
25544	ISS	406.6	417	51.6	15.54	15
37820	TIANGONG-1	324	351	42.8	15.80	14
41765	TIANGONG-2	399	402	42.8	15.58	2
32477	PSLV_RB	387.2	431.1	41	14.93	9
26960	PSLV_RB	515.1	519.7	97.7	14.76	5
36800	PSLV_RB	592.8	592.8	98	15.31	7
38757	PSLV_RB	641.2	648.3	98.1	15.65	3
23828	PSLV_RB	823.0	824.0	98.7	14.22	1
41172	PSLV_RB	401.1	555.7	14.7	15.51	23
25759	PSLV_RB	706	734.0	98.4	14.53	1
29713	PSLV_RB	602	638	97.8	14.84	2
28651	PSLV_RB	605	710	97.9	14.73	1
38249	PSLV_RB	347	364	97.4	15.73	1
38757	PSLV_RB	639	649	98.1	14.76	2
40058	PSLV_RB	625	657	98.1	14.78	1
40720	PSLV_RB	634	640	98.0	14.79	1
41791	PSLV_RB	666	728	98.2	14.60	1
42052	PSLV_RB	483	499	97.5	14.79	1
36801	PSLV_DEB	463	470	98.1	15.35	1
29053	MINOTAUR_RB	364	371.1	72	15.51	2
16111	SL3_RB	409.6	432.1	97.4	14.93	4
25723	SL8_RB	411.6	424.3	48.4	14.32	2
25560	SWAS	590.5	599.2	69.9	15.50	2
13991	COSMOS 1452	778.1	799.7	74	14.89	1
13770	COSMOS 1437	414	423	81.2	15.51	5
39491	COSMOS 2494	592.0	621.0	82.4	14.89	3
15369	COSMOS 1606	513.0	538.0	82.5	15.15	1
05398	RIGIDSPHERE	740.6	833.6	87.6	14.31	1
25506	PEGASUS_RB	729.2	762.2	25	15.00	1
39086	SARAL	791.8	792.7	98.5	15.45	7
23324	IRS P2-RB	801	883	99.1	14.17	4
28485	SWIFT	566.3	581.8	20.6	15.09	9
26102	MTI	430.4	443.6	97.6	14.34	4
25080	HST	572	576.1	28.5	15.09	10
25342	IRIDIUM70	786.3	783.3	86.4	15.70	2
38248	RISAT1	570.9	577.2	97.6	14.79	9
34807	RISAT 2	469	479	41.2	15.33	1
23757	XTE	364.2	367.9	23	15.53	4
21688	IRS 1B	893	927	103.1	13.96	2
23323	IRS P2	819	820	98.8	14.24	1
23751	IRS 1C	823	824	98.7	14.22	1
24971	IRS 1D	747	824	98.4	14.34	2
25758	IRS P4	722	727	98.2	14.53	2

28051	IRS P6	744	826	98.6	14.34	2
28649	CARTOSAT 1	624	626	97.9	14.83	2
32783	CARTOSAT 2A	632	649	97.9	14.78	2
35931	OCEANSAT 2	727	732	98.3	14.50	1
42063	SENTINEL 2B	795	797	98.6	14.31	1
25560	SWAS	589	599	69.9	14.93	2
25721	ABRIXAS	317	322	48.4	15.85	3
32289	YAOGAN3	635.3	637.6	98	15.72	4

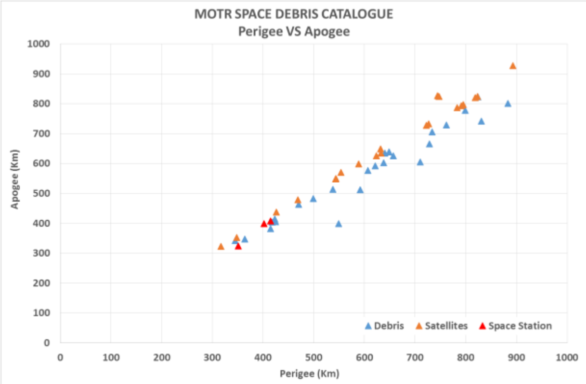

Fig.7. Distribution of Space Debris observed by MOTR.

ORBIT PREDICTION & TLE GENERATION

The small arc of MOTR tracked data is edited for compensating the known fixed biases in angles and range dopplar compensation for range befor processing. The Initial Orbit determinitation (IOD) process gives the initial state vector for the target for an epoch. IOD is computed by selecting 3 points from radar measurement using Herrick Gibbs method [7]. The IOD state vectors is propogared using High Precise Orbit Propogator (HPOP) for getting the estimate parameters which is corrected with radar measurement. The final state vector at the end of radar measurement is propogated to form a complete orbit. Two Line Elenets (TLE) is computed for this generated orbit. The first TLE generate for ISS tracking with the MOTR has an accuracy of 0.5 deg error compared with NORAD TLE, eccentricity achieved was 0.019 against 0.000743. The priliminary reasons for this error observed in OD is minor offsets observed in angular measurements and very short duration of data for orbit generation due to skin mode tracking. The accuracy has further improved by calibrating the radar for offsets in Range and, Angle coordinates. The orbit prediction accuracy has improved after calibrating the active array. As on Aug 2017 the accuracy achieved for ISS orbit is +/-0.05 deg error in inclination, +/-0.01 error in eccentricity and +/- 10km error in appogee and perigee.

FUTURE PLANNED ACTIVITIES

As the activities planned for future, we have aimed to observe all the 733 objects in LEO orbit in near future. These objects will be tracked continiously and their TLE's will be catalogued. This indegineous catalogues will be used by ISRO for their space assets management. The tracking data shows that the attitude of the space debris is always changing which results in the cyclic variation in effective RCS which is observed through the variatuion in the received signal strength. This variation needs to be studied and modeled based on the targets information like shape and size to estimate the best suite value of RCS for the debrie.

CONCLUSION

This paper has brought out the maidin space debris tracking attempt and its observations made by ISRO with Multi Object Tracking Radar (MOTR). It has also described the methods adapted for processing the space debris tracked data for orbit determination and TLE generation, and the improvements carried out for improving the accuracies in Orbit determination. This paper has brought out that MOTR is capable to track space debris with large RCS greater the $1m^2$ up to an altitude onf 800 km.

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